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The role of mathematical skill in sex differences on Raven's Matrices

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ABSTRACT

This study replicated a previously reported male advantage on certain items of Raven's Matrices and found no sex differences in performance on other items. We refer to the latter as analytic (1) items and the former as analytic (2) items. Reasons for the male advantage were investigated by correlating scores obtained by male and female high school students on analytic (1) and analytic (2) items with their scores on tests of spatial, verbal and mathematical ability. There were no sex differences in the magnitude of the correlations between scores on analytic (2) items and the two spatial and verbal tests. In contrast, males but not females showed a significantly higher correlation of maths with analytic (2) than with analytic (1). The results suggest the Raven's Matrices may engage different, more specific cognitive processes in males and more general cognitive processes in females.

1. Introduction

Most research on sex differences in performance on IQ tests has sought to understand their distal causes, either biological causes such as hormonal effects or differences in the lateralisation of the brain, or social causes such as cultural expectation (see Halpern, 2000). Here, we focus instead on proximal causes, by considering differences in the cognitive processes employed by the two sexes to solve items in IQ tests. Rather than focussing on the troubling question of gender differences in IQ per se, our intention is to enhance our understanding of the cognitive processes that underpin performance on the Raven's Matrices. Previous studies have reported a small male advantage only on particular kinds of item in the Raven's Matrices (Mackintosh & Bennett, 2005; Vigneau & Bors, 2008). This suggests the possibility that, in males at least, Raven's Matrices measure some specific cognitive processes, rather than simply general ability or '*g*'. This study assessed whether the male advantage on these items may be due to the utilisation of particular cognitive processes on these items by males but not females, in particular spatial and mathematical processes.

The Raven's Matrices are widely regarded as a measure of general intelligence, or *g*. Indeed, some authors have claimed that the Raven's Matrices measure virtually nothing but *g* (Jensen, 1980, 1998). Multidimensional scaling analysis of various IQ tests places the Raven's Matrices at the center of the solution, reflecting the fact that they are more closely related to all other tests than the latter are to each other (Snow, Kyllonen, & Marshalek, 1984). This is certainly consistent with the idea that the Raven's Matrices measure some cognitive process that underpins, to some degree, all tests of intelligence. However, there are several good reasons for supposing that the Raven's Matrices do not in fact measure only one process. One is that several factor analytic studies have shown that the Raven's Matrices measure more than one factor (Lynn, Allik, & Irwing, 2004; Van der Ven & Ellis, 2000; see also Hunt, 1974). Another is the observation of sex differences on certain items. Lynn et al. (2004), in their study of the Standard Progressive Matrices (SPM), found that, whilst there were no sex differences on items loading onto one of their two analytic factors, males obtained higher scores than females on items that load onto their second analytic factor.

Mackintosh and Bennett (2005) confirmed that sex differences were found on only certain types of item in the Raven's Matrices. They argued that the rules described by Carpenter, Just, and Schell (1990) in their analysis of Raven's Advanced Progressive Matrices (RAPM) could be used to distinguish between the items loading onto the two factors identified by Lynn et al.'s (2004), labelling these analytic (1) and analytic (2) items. Analytic (1) items, on which no sex differences were observed in either Lynn et al.'s (2004) or Mackintosh and Bennett's (2005) studies, require pairwise progression or distribution of three rules; analytic (2) items, on which both studies found males outscored females, required either addition/subtraction or distribution of two rules.

Whilst Carpenter et al.'s (1990) rules have proved useful in distinguishing between items loading onto these two analytic factors, they do not in themselves provide any insight into the nature of the cognitive processes involved in the two factors, since they simply describe the rules which need to be induced rather than the processes involved in the induction. The presence of sex differences on certain items, however, provides an opportunity to investigate what those processes may be. One obvious possible reason for the male advantage on analytic (2) items is that these items

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may primarily engage visuospatial processes. Several authors have indeed suggested that the small overall male advantage on Raven's Matrices is due to the (partially) visuospatial nature of the test (Colom, Escorial, & Rebollo, 2004; Flynn, 1998). Mackintosh and Bennett (2005) investigated this possibility by correlating participants' scores on a mental rotation test (MRT-A: Vandenberg & Kuse, 1978) with their scores on analytic (1) and analytic (2) items. However, they found that, although overall Raven's scores were more highly correlated with MRT scores in males than in females, there was no suggestion, in either sex, that MRT scores correlated more strongly with scores on analytic (2) items than with analytic (1) items. This suggests that the MRT does not tap the type of visuospatial processing that is required to solve Raven's analytic (2) items. Certainly intuitively at least, no item in the Raven tests requires mental rotation for its solution.

This raises the possibility that other tests of spatial visualisation, sharing less in common with tests of mental rotation, might be more successful at differentiating Raven's items loading onto the analytic (2) factor from those loading onto analytic (1). We tested this here by giving two further spatial cognition tests; the Space Relations test from the DAT (Hyde & Trickey, 1995) and the punched-hole test from the Ekstrom, French, and Harman (1976) battery of factor-referenced tests. If the visual-spatial reasoning involved in items which load onto analytic (2) factor is similar to that assessed by these spatial tests rather than mental rotation, we predict that scores on those items will correlate more highly with them than will scores on those items which load onto the analytic (1) factor. More important, we predict that this will be particularly true for males, and may not be true for females at all.

However, a further possibility is that there is nothing peculiarly spatial about analytic (2) items at all and that their solution depends on some other cognitive processes. A second possible reason for the male advantage on analytic factor (2) items is that these items may involve the kinds of processes involved in certain kinds of mathematics in which males are known to outperform females. The literature concerning male/female differences in mathematics is both contentious and mixed. However, there is at least some consensus that males, although worse than females on computation, are better than females on mathematical reasoning problems (e.g., Halpern, 2000). In particular, there is evidence that males outscore females on problems that are presented verbally, but require translating into mathematical terminology for their solution (Low & Over, 1993). It seems plausible to suppose that this might indeed be a facility that would benefit performance on Raven's tests, and perhaps particularly on analytic (2) items (i.e. A/S and D2 items). As above, we predict that if mathematical processes of this kind are marshalled on analytic (2) items, then these items will correlate better with scores on such mathematical tests than will scores on the other items which load onto analytic factor (1) and that this will be particularly true for males.

In summary, this study sought to replicate previous findings of a male advantage on analytic (2) items in the Raven's Matrices, and, further, predicted that males' performance on these items will be correlated with their spatial and mathematical ability, whereas there will be at best only a weak correlation in females. No sex difference was expected on analytic (1) items, nor any differential correlations of spatial and mathematics performance between the sexes on analytic (1) items.

2. Method

2.1. Participants

A total of 242 sixth-form (senior high school) students, aged between 16 and 18 and attending non-selective sixth-form colleges in East Anglia, England, participated. There were 125 males and 117 females.

2.2. Materials

Two specially constructed sets of Raven's items, each set containing 18 items were printed as booklets (see Mackintosh and Bennett, 2005). Of the total of 36 items, five were drawn from the SPM (E8, E9, E10, E11, and E12) and 31 from the RAPM (items 3–35). This selection ensured approximately equal numbers of items that involve Carpenter et al.'s (1990) four types of rule. Within each set, the items were ordered so that the different rules were distributed equally throughout each test to ensure that all participants completed some items involving each rule. Two visuospatial tests were used: the Space Relations test from the DAT (Hyde and Trickey, 1995) and the punched holes test from the Ekstrom et al. (1976) battery of factor-referenced tests. The DAT Verbal Reasoning test was used to assess verbal ability. A 16-item test of mathematics was devised, comprising problems in a similar format to those set in British mathematics examinations for 16 year old students.

2.3. Design and procedure

Each participant was tested in two sessions, with a minimum of 24 h between each session. In one session, they completed one set of Raven's items, the DAT verbal and the punched holes test and, in the other, the remaining set of Raven's items, the DAT spatial and the mathematics tests. After practice items, participants were allowed 25 min to complete each set of Raven's items, 20 min to complete the DAT spatial and verbal tests, 6 min to complete the punched holes test and 10 min to complete the mathematics test. There were four practice items for the Raven's tests, three for the DAT verbal, two for the DAT spatial and one for the punched holes tests.

3. Results

An ANOVA was conducted on the percentage of items answered correctly by male and female students on all Raven's items, and on analytic (1) and analytic (2) items separately, the DAT spatial, DAT verbal, punched holes and mathematics tests with sex and test as factors. This revealed a main effect of sex ($F(1240) = 4.19$, $p = .04$, $\eta^2 = .02$) and test ($F(4960) = 67.15$, $p < .001$, $\eta^2 = .22$) and no interaction ($F(4960) = 1.82$, $p = .12$). However, t-tests established that, while there were no overall sex differences on the Raven's, DAT verbal or spatial tests ($t(240) = 1.73$, 0.75, and 0.64, respectively), there was a significant male advantage on the punched holes ($t(240) = 2.47$, $p = .01$) and mathematics tests ($t(240) = 2.19$, $p = .03$).

A second ANOVA was conducted on the scores from the Raven's test alone, with factors of analytic factor (analytic (1) versus analytic (2)) and sex. There was a main effect of analytic factor ($F(1240) = 83.29$, $p < .001$, $\eta^2 = .25$; average scores were 66.15 for analytic (1) and 57.4 for analytic (2), respectively), but not of sex ($F(1240) = 2.90$, $p = .09$). There was an interaction between sex and analytic factor ($F(1240) = 9.08$, $p < .01$, $\eta^2 = .03$). Subsequent t-tests revealed that there were no differences between males and females in their performance on analytic (1) items ($t(240) = 0.43$, $p = .67$), and a male advantage on analytic (2) items ($t(240) = 2.48$, $p = .01$).

Pearson correlation coefficients were calculated, separately for males and females, between percent correct scores on analytic (1) and analytic (2) items and scores on the DAT verbal, DAT spatial, punched holes and maths tests. These correlations are